GEOLOGY OF THE LUNAR REGIONAL DARK MANTLE DEPOSITS AS SEEN BY CLEMENTINE UVVIS DATA.
C. M. Weitz, J. W. Head III, and C. M. Pieters, Department of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 (Catherine_Weitz@Brown.edu).

Introduction: We have used calibrated Clementine UVVIS data to map the geology and analyze spectra from several regional Dark Mantle Deposits (DMD) on the Moon, including Taurus-Littrow (TL), Rima Bode (RB), Sulpicius Gallus (SG), Aristarchus Plateau (AP), and Orientale (OR). Regional DMD formed from pyroclastic eruptions and are composed of either volcanic glasses or crystallized beads. Unlike smaller localized dark mantle deposits, like those in Alphonsus and Franklin craters, which are only a few kms in diameter and are produced from vulcanian eruptions [1, 2], regional DMD cover tens of km and indicate higher volume fluxes and plume heights. The crystallinity of the volcanic beads in a DMD is a very useful parameter for determining the cooling rates within the volcanic plume, with glasses indicating high cooling rates in a low optical density plume. Telescopic spectral data of the deposits [3, 4, 5] indicate that TL and RB are dominated by crystallized black beads, SG is an equal mixture of glasses and black beads, while AP is dominated by the glasses. More recent Clementine data of the OR deposit on the lunar farside has shown that it is composed of volcanic glasses similar to those in the AP deposit [6].

Taurus-Littrow Deposit: The TL deposit is the only RDMD where samples were collected. The Apollo 17 mission retrieved several soil samples of the dark mantle and has shown that it is a mixture of high-Ti orange glasses and their crystallized equivalents (black beads), with the crystallized beads dominating the deposit [7, 8]. A drill core taken on the rim of the 120 m diameter impact crater Shorty showed that the orange glasses erupted earlier and then progressively changed to an eruption producing the black beads [9].

High-resolution Clementine UVVIS images (106 m/pixel) of the Taurus-Littrow Valley, including the Apollo 17 site, have been used to correlate the Clementine data to ground truth observations and high resolution Apollo photographs. In general, our interpretations using the Clementine data agree well with the geologic map by Wolfe et al. [10] produced using Apollo photographs. The DMD is darkest just north of the light mantle deposit and in the southeast of the valley away from the crater clusters. In contrast, the central portion of the valley floor is dominated by the spectra of the crater clusters and their ejecta. Adjacent to the highlands (South and North Massifs), the spectra is dominated by mature highland soils that have massed wasted onto the valley floor and mixed with the local soils. Ejecta from Shorty Crater is visible in the Clementine data because of its low albedo due to the dark mantle it exposed underneath the light mantle deposit.

The Clementine data also show a mafic signature in the walls of the craters Camelot, Sherlock, Steno-Apollo, Powell, Faust, and Emory. These craters, all of which are between 0.5-1 km in diameter and most of which are considered to be secondaries from Tycho [10], have exposed the underlying basalts in the valley. The crater Steno-Apollo has the highest 0.75/0.95 µm signature of all the crater clusters in the valley, suggesting that it is the youngest. A 0.1 km diameter crater and its smaller neighbor in the southern edge of the Sculptured Hills were mapped among the youngest craters in the valley [10]. In the Clementine data, the two craters appear as one larger crater with a very strong noritic signature. The northeastern edge of Bear Mountain also has a noritic signature, perhaps associated with a young crater, while the rest of the Mountain is composed of anorthositic breccia.

The Clementine UVVIS data (180 m/pixel) for the TL DMD to the northwest of the Taurus-Littrow valley show a low reflectance, high UV/VIS ratio, and a relatively featureless spectra from 0.4 to 1.0 mm, characteristic of the black beads. Fresh craters in the surrounding low-Ti mare of Serenitatis have a basaltic spectra while the larger fresh craters in the DMD appear more noritic in composition. The surrounding highlands have either a spectra for anorthosite, norite, or a mixture of the two. Therefore, it appears that many of the larger craters in the DMD are penetrating to underlying noritic highlands. In contrast, the craters in the Taurus-Littrow valley exposed underlying mare. Young small craters in the highlands and DMD have exposed fresher dark mantle beneath the regolith while small craters in the north have penetrated through a large 7.2 km diameter crater's bright ejecta blanket, exposing the underlying DMD.

Rima Bode Deposit: The Rima Bode DMD has a spectra similar in shape to the TL DMD but slightly higher in reflectance; hence, the DMD is dominated by the crystallized black beads and may have been mixed with more highlands than at TL. Overall, the deposit is also very similar in shape and size to the TL DMD, suggesting that the two DMD had a similar eruptive history. The DMD has been partially covered by mare to the west and south, although small kapukas of the DMD are still visible in the south. The spectra for the perched lava pond mapped by [4] has a similar spectra to the low-Ti mare soils of Serenitatis. Moving radially outward, the DMD is higher in reflectance and more patchy, supporting that it is thinner and has mixed with the surrounding highlands [3]. The spectra for the highlands indicate a mixture of anorthositic breccia and norite.

Sulpicius Gallus Deposit: Photographs of the deposit taken during the Apollo 17 mission showed layers of orange and red glasses exposed in several crater walls [11]. Spectra from the Clementine UVVIS data show that the deposit has the highest reflectance of all the RDMD analyzed in this study and a glass band is readily visible. The high reflectance may be due to the extensive mixing of the deposit with the surrounding highlands of southwestern Mare Serenitatis. Unfortunately, we are unable to distinguish between the red and orange glass layers in the DMD at this low spatial (155 m/pixel) and spectral resolution. Luchitta and Schmitt [11] also identified dark material on the inside of a 1.5 km diameter fresh impact crater located in the mare and suggested that a dark mantle layer occurred beneath the younger mare at the edge of the Serenitatis basin. However, the Clementine data show a bright interior for this crater with a strong low-Ca pyroxene absorption, indicating that the dark interior is in fact young, fresh basalt. The Apollo 17 photos also showed a 5.5 km-long kidney-shaped depression with orange and red layers visible in its walls [11]. Clementine data for the depression show a low 0.4/0.75 µm and high 0.75/0.95 µm ratio around the walls, supporting a mafic composition in the walls but no dark mantle could be resolved.

Mare ponds in the highlands are visible to the south and in the western portion of the DMD. Numerous small craters with a higher reflectance, steeper UV/VIS, and stronger glass band compared to the surrounding DMD appear to have excavated fresher dark mantle. The large 12 km diameter crater, Sulpicius Gallus, in the mare has a spectra of both norite and basalt in its walls, indicating that the crater penetrated to the depth of the contact between the mare and highlands.

Aristarchus Plateau Deposit: Telescopic observations showed that the Plateau was covered by orange/red volcanic glasses [4, 12]. Preliminary Clementine observations of crater ejecta in the DMD were used to estimate a thickness of 10-30 m for the deposit [13]. The DMD is darkest to the northwest, most likely due to the mixing and burial of the dark mantle by the Aristarchus crater located to the southeast. Numerous small bright hills interspersed throughout the DMD are composed of anorthositic material and presumably represent ejecta from either Aristarchus crater or from the formation of Imbrium basin. The walls of Vallis Schroteri and the smaller rilles have a mafic signature supporting that mare exists beneath the DMD [13]. There are several small patches of dark mantle with lower 0.4/0.75 µm ratios nestled in the DMD. These patches may reflect variations in glass type, maturity, and/or mixing.

Orientale Ring Deposit: The ring deposit is centered on the Montes Rook in the southwestern portion of the Orientale basin. Previous observations of the OR deposit by the Galileo spacecraft showed that it was composed of a mixture of pyroclastics and highland materials [14, 15] but the crystallinity of the beads could not be determined. The Clementine UVVIS data now show that the DMD is composed of volcanic glasses similar to those at AP, indicating high cooling rates in a low optical density plume. The deposit is 154 km across and has an 18-km long elongate depression at its center which we interpret as the source vent of the DMD. The deposit is darkest and widest in the north but thinner and brighter elsewhere due to mixing with the highlands.

The vent has a noritic signature similar to that found in the local crater walls and no lavas can be seen surrounding the vent, indicating that the vent is a collapse feature and no mare erupted in association with the emplacement of the glasses. Based upon the distribution of the deposit and using the elongate central depression as the source vent, the deposit can best be modeled by an eruption from a foam layer at the top of a dike that stalled a few kms below the surface. The volcanic plume was umbrella-shaped, similar to those seen on Io, with eruption velocities from 350-400 m/s and a plume height of 40 km [6].

Conclusions: The Clementine UVVIS data with its 5-channel spectral resolution and relatively high spatial resolution has enabled us to provide new information about the regional DMD and the geology of the surrounding region. In particular, the identification and modeling of the OR deposit, which is the first annular regional DMD identified on the Moon, has provided insight into another style of lunar pyroclastic eruption. Continued analysis of the other orbits that cover these deposits as well as a study of the remaining regional DMD will help us to understand how they formed and further our knowledge about the explosive volcanic history of the Moon.

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